Real-time landscape-size convective clouds simulation

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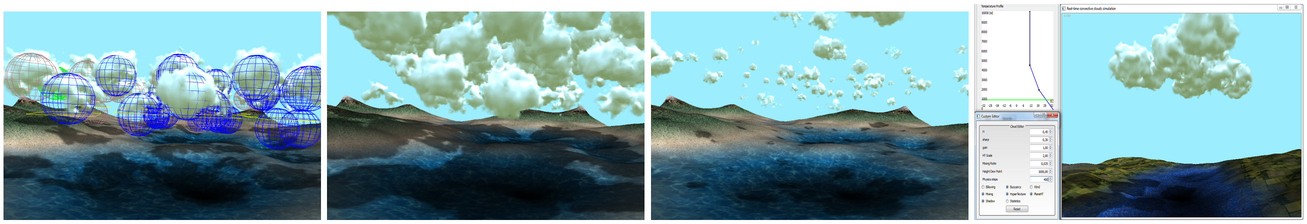

***Figure**: Clouds condensate when reaching the dew point altitude, rise up to equilibrium altitude, then decay and die due to the effects of entrainment and detrainment, demonstrating the entire cloud lifecycle. Our interactive tool allows the user to play around with intuitive parameters to generate plausible evolving fields of cumulus clouds.*

1 INTRODUCTION

Cumulus clouds are ubiquitous in outdoor naturalistic scenes. However, realistic and scalable cloud simulation continues to be a challenge in computer graphics. Computational fluid dynamics models (CFD) are computationally intensive and hence impractical for real time methods. Eulerian models [Harris et al. 2003] on the other hand require modeling even the transparent volume, placing serious restrictions on the domain size. More importantly, both these methods do not offer convenient handles on initial, border and atmospheric conditions which play a key role in the natural evolution of the cloud phenomena. We introduce Lagrangian framework for the cloud physics and rendering at landscape size. The use of Lagrangian formalism, aerology physics, and separation of environment from the dynamics, brings more robustness, offers meaningful high-level handles for user control - environment profile and evolution, cloud base and top.

2 CLOUD PHYSICS

Our physics operates at the level of macro spherical units called parcels which account for the clouds and thermals and not for the whole sky. These parcels interact with each other through *smoothed particle hydrodynamics (SPH)* forces of pressure and viscosity. The environment is represented implicitly using piecewise linear profiles of temperature and wetness and hence eliminates any requirement for explicit storage or tedious manual setting. Since the particles cover only a part of the atmosphere, the continuum of pressure and drag forces is provided by modeling the exposed parcel-environment interaction, thereby completing these forces. The parcels interact with the surrounding environment through the process of entrainment and detrainment. This results in the exchange of heat and vapour mass through the parcel area exposed to the environment. Finally, the buoyant force is applied on each parcel as a function of potential temperature difference(Θ) with the surrounding air. In addition to user chosen environment profile, the system offers a procedural thermal emitter with several handles: birth area, frequency of emission, average and deviation values for mass, temperature and wetness.

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3 VISUALIZATION

The micro level deals with the procedural generation of cloud details on top of existing macro structure of parcels. For this, before the ray-tracing step we transfer to GPU the active list of condensed spheres together with their dew-point plane and filling ratio. The hypertexture [Perlin and Hoffert 1989] is computed on the fly, and is controlled by a few macroscopic handles such as particle radius, dew-point plane and filling ratio. The resultant density values are visualized using volume rendering. We also determine the normals used for the local shading by applying finite differences on the computed density.

4 RESULTS

The proposed method is implemented on an Intel Xeon 2.67 GHz machine with 6 GB RAM and NVidia GeForce GTX 670 graphics card using C++. Using our approach, realistic effect can be produced by using just few parcels which significantly reduces the physics cost. For this reason we execute the entire physics pipeline on CPU. The rendering engine is based on GigaVoxels [Crassin et al. 2009] which is written for the CUDA version 6.0. The hypertexture production and raycasting based visualization takes a larger share of computational time. Our method achieves interactive frame rates for the above figure where 75 parcels are dynamically created, simulated and visualized.

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